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PLANETARY SPACECRAFT COST MODELING UTILIZING
LABOR ESTIMATING RELATIONSHIPS

Final Report

NASA/ASEE Summer Faculty Fellowship Program--1990

Johnson Space Center

M3452869

Prepared by:	Raymond Williams, Ph.D.
Academic Rank:	Associate Professor
University & Department:	Mississippi Valley State University Computer Science and Mathematics Department Itta Bena, Mississippi 38941
NASA/JSC	
Directorate:	New Initiatives Office
Division:	Project Planning & External Affairs
JSC Colleague:	Jared R. Woodfill
Date Submitted:	August 10, 1990
Contract:	NGT 44-005-803

ABSTRACT

A basic computerized methodology is presented for estimating labor hours and cost of unmanned planetary and lunar programs. The user friendly methodology designated Labor Estimating Relationship/Cost Estimating Relationship (LERCER) organizes the forecasting process according to vehicle subsystem levels. The level of input variables required by the model in predicting cost is consistent with pre-Phase A type mission analysis. Twenty-one program categories were used in the modeling: sixteen spacecraft subsystem categories (structures and devices, thermal control, cabling and pyrotechnics, propulsion, attitudes and articulation control, telecommunication, antennas, command and data handling, RTG, solar batteries, aerodeceleration, radar, line-scan, vidicon, particle and field, remote sensing, and direct sensing and sampling); and five support categories (program management, system support and ground equipment, launch +30 days operation and ground software, image data development, and science data development). To develop this model, numerous LER and CER studies were surveyed and modified where required. The most recent models that estimated cost of historical data to within 20% of the actual cost were selected. The result of the research along with components of the LERCER program are reported. On the basis of the analysis the following conclusions were established: (1) spacecraft cost is highly correlated with man (labor) hours; (2) no user friendly program was found that linked LERs with CERs to produce spacecraft cost as computer output; (3) the cost of a spacecraft is best estimated by summing cost of individual subsystems; (4) the group accumulation labor estimation method proved to be a useful method for finding total manpower labor hours and cost of a spacecraft; (5) the cost of 1 kg mass across subsystems can vary from \$152K (structure and devices) to \$6.6M (thermal control, cabling and pyrotechnics); (6) program labor cost constitutes approximately 30 percent of the total program cost.

INTRODUCTION

Space program cost estimation in pre-Phase A stage of development remains a challenge for cost forecasters. A central idea presented in this study is that cost forecasting can be improved by selecting manhours as the primary cost unit. One major advantage of manhours as the basic cost unit over forecasting total program dollar amount is the separation of inflationary factors. Two programs costed at different times can only be compared if some inflationary factor is applied to the older program. The ideal inflation factors are often difficult to formulate for total program cost and often fail to be good representative of the actual financial conditions within industry. Industry still has not been able to mass reproduce spacecraft and consequently the total cost of each subsystem is not significantly decreased through additional production.

The purpose of this study was (1) to model spacecraft cost as a function of manhours; (2) to interconnect manhour equations and cost equations; (3) to develop a computer program that uses LER output as input into CERs producing the cost of a spacecraft as final output; and (4) to extract from the literature those labor estimating relations (LERs) that determine the total cost of a spacecraft by summing the cost of its individual subsystems.

LABOR ESTIMATING RELATIONSHIPS (LERs)

Early and adequate estimation of program cost requirements should be of major concern to both the government and government contractors. Experience indicates that final cost of advanced technology activities has been extremely higher than that originally predicted. Somehow, prediction procedures have resulted in large errors in costing spacecraft programs. Thus, there is a rapidly growing need for a credible spacecraft cost model. It should be noted that a cost model does not necessarily represent factual information, but rather it is based on experimental approximations. Costing spacecraft by using dollar amounts as the basic cost unit is the method reported by most cost forecasting studies. This paper uses, instead of dollar expenditure, manhours (labor hours) as the basic cost unit. Forecasting labor hours has several advantages over directly forecasting total program dollar amount. One such advantage,

and most important, is that manhours separate inflationary factors from the model. Inflationary factors are very difficult to formulate for total program cost and often time are not consistent with inflation rates within industry. Additional information reported by industry reveals that space industry is still unable to mass produce spacecraft. That is, the cost to make additional copies of the same flight unit is not significantly reduced from that of the original unit. Thus, it appears that project hardware cost is directly related to the manhours involved in the development, fabrication and testing. Hence, the manpower approach to cost forecasting should provide management with a tool to evaluate the cost of new projects in light of formulated manpower estimating relationships.

COST ESTIMATING RELATIONSHIPS (CERs)

Historically, early estimates of spacecraft project cost have been considerably less than the final actual cost. Spacecraft have been very expensive to produce because of stringent weight and performance requirements, heavy emphasis on reliability, and small production quantities. Various parametric cost estimating models have been developed from experience of the past 30 years, and those models reproduce the cost of the traditional spacecraft with acceptable accuracy. Due to the limited data base of manned space vehicles, a spacecraft cost estimating procedure based on historical data often contains errors. Mathematical relationship errors will exist in any estimating procedure which attempts simplification of actual cause and effect by empirical approximation. A good cost model, of course, is one that strives to minimize these inevitable errors. Cost regression equations for spacecraft subsystems are typical of the type

$$Y = AX^b \text{ or } y = A + BX^c$$

Where Y = cost and X = weight or some other subsystem characteristic. Those cost models that were shown to predict the cost of historical vehicles to within 20 percent of the actual cost were selected or developed for this study.

LERCER PROGRAM APPLICATION/OPERATION

All spacecraft information for use with the LERCER computer program is found within the LERCER folder on diskette. To operate the program open the LERCER folder and all files therein. Input data description is found at the top of each column. Row 5 of column A gives instructions for handling spacecraft flight units.

The LERCER program strives to use features resident in EXCEL and the Macintosh system in a user friendly fashion. Among these features is the "GOTO" instruction. Selecting the "GOTO" from the "FORMULA" column on the menu bar opens a listing of all 21 subsystems and other pertinent categories listed in alphabetical order. Scroll through this list and make your selection. Control will then be transferred to this selection in the program. You may at this point make modifications in the input data if you so desire.

Each file with the surname TOTAL represents an accumulation of all spacecraft calculations for the total of a particular spacecraft program. Sample calculations for two planetary programs are included in LERCER: one of which is the Mars Rover Sample Return (MRSR) program developed by Martin Marietta Corporation and the second calculation is for the Mass Matrix (MM) program developed in-house at JSC.

The LERCER program has a fundamental feature: to use pre-Phase A weight estimates for each subsystem to estimate manpower hours; to input the forecasted manhours into a corresponding cost equation for forecasting cost of planetary subsystems; and finally, to calculate the total forecasted cost.

The LERCER program features facilitate this fundamental operation. Initial input data is entered in ledger fashion in a single column of the EXCEL spreadsheet matrix. The input data consists of listed constants selected by the user, adjustment factors, and the subsystem mass. Each LERCER equation is listed adjacent to the entry data column to assist the user. Again, a designated ledger column serves for listing of all LERs and CERs.

Total cost includes two categories: non-recurring (design, development, test, and evaluation (DDTE)) cost and recurring flight hardware (FH) cost. Each subsystem has two cost forecasting equations listed on separate LERCER lines. The total cost for each spacecraft is found by summing the total cost of individual subsystems. Similarly, total recurring cost of each spacecraft is found by summing the recurring cost of individual subsystems. Non-recurring cost may be obtained by subtracting recurring cost from the total cost.

SUMMARY AND CONCLUSION

Early estimates of planetary spacecraft programs have been significantly less than the final actual cost. The ratio of actual cost to forecasted cost has been reported as high as 4:1. Manhour expenditures as a major costing unit was found to substantially lower this ratio. The manhours needed to build a planetary spacecraft may be adequately estimated and costed for initial pre-Phase A design utilizing credible historical data and regression analysis within a programmed methodology. The LERCER is such a system developed by this study. This program was developed for the New Initiatives Office (NIO) at JSC. Content of the methodology includes a slightly modified version of Science Applications Incorporated (SAI) manhour model and cost estimating relationships developed by the study. Dry mass is expressed in kilograms and cost in 1990 million-dollar units.